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ZOOPLANKTON DISTRIBUTION IN A MARINE PROTECTED AREA: THE BERLENGAS NATURAL RESERVE (WESTERN COAST OF PORTUGAL)

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ABSTRACT

Zooplankton distribution in the Berlengas Natural Reserve (Portugal) was studied over a period of one year (February 2006 to February 2007). Monthly sampling was performed at 6 stations, differentiated according to depth and distance to the coastline. The aim of this study was to investigate the overall zooplankton variability through its different dimensions (space vs. time). The Partial Triadic Analysis (PTA) was used to study the spatial variability of the zooplankton community and its dynamics in time and the dynamic trajectories of the zooplankton species for each site. It was possible to distinguish a neritic-ocean gradient of the zooplankton composition and a temporal variability. Four distinct periods can be highlighted considering the distribution of the dates and the arrangement of the species: (i) the first one comprised August to November, (ii) the second one was related to June and July, (iii) the third one associated with spring (April and May) and, (iv) the latest one was related to winter (February, March and December 2006 and January and February 2007). The PTA method showed the similarities between the successive data tables and proved to be useful for investigating biotic structures and detecting spatial-temporal patterns in zooplankton distribution.

KEYWORDS: Berlengas Natural Reserve, partial triadic analysis, spatio-temporal distribution, zooplankton.

1. INTRODUCTION

The Berlengas Natural Reserve (BNR) is an archipelago formed by 3 groups of islands (Berlenga, Estelas and Farilhões) located on the western coast of Portugal. The Reserve was created in 1981, aiming to preserve a rich natural heritage and to ensure sustainable development of human activities in the area. More recently, BNR was proposed to be a Biosphere Reserve. This denomination is attributed by UNESCO to sites where is recognized the existence of innovate approaches to conservation and sustainable development. It has a total area of 9560 hectares, 9456 of which are marine. It is located on the Portuguese continental shelf at an average distance of 5.7 miles from the mainland (Cape Carvoeiro - Peniche). The geographical location gives singular characteristics to the archipelago, which enhanced the interest of ecological studies, because it is located in a zone with a temperate maritime climate and is influenced by seasonal coastal upwelling controlled by the atmospheric circulation associated with the Azores anticyclone. Persistent northerlies (upwelling favourable) are observed in summer (June to September) [1,2]; it is, however, during the non-upwelling season (late winter-spring) that a large amount of meroplankton species are observed over the shelf [3]. Concerning coastal circulation, other important aspects are the Portugal Current flowing off the continental slope westward of 10ºW [4], the Iberian Poleward Current that flows over the slope [5] and the Western Iberia Buoyant Plume (WIBP) [1]. Moreover, it is located at the top of the escarpment of the Nazaré Canyon, one of the most worldwide important submarine canyons in the transition zone between the Mediterranean and European subregions. This location contributes to the remarkable productivity and diversity of marine species and habitats and to a landscape unique in the region. Previous studies have investigated the distribution and composition of zooplankton along the Berlenga shelf area [6]; however information on the zooplankton community remains limited. This work intended to be a preliminary study in this area and pretended to analyze the variations in zooplankton species abundance and the different compositions at shelf and oceanic sites through its different dimensions (time

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vs space). To achieve such objective the spatio-temporal zooplankton community structure was assessed by means of a Partial Triadic Analysis (PTA) [7-9]. The PTA is a method of analysis for three-way data sets presented as a sequence of two-way tables. It is useful when analyzing the same variables (in this study, the species density) measured on the same items (dates or sites) and done for the same occurrences (sites or dates). Its general aim is to determine the proportion of variability in the variables that depends on space or on time.

2. MATERIALS AND METHODS

2.1. Survey design

From February 2006 to February 2007, zooplankton samples were collected monthly from 6 stations: E1 (39°25´N 9°30´W), E2 (39°25´N 9°31'W), E3 (39°25'N 9°31´W), E4 (39°25´N 9°30´W), E5 (39°25´N 9°27´W) and E6 (39°21´N 9°23´W), located along a transect perpendicular to the coastline (between the Peniche coast and Berlenga islands) (Fig. 1). September 2006 was not sampled due to poor ocean conditions. The samples were obtained from inshore (E6), shelf (E5) and offshore regions (E1, E2, E3 and E4). Zooplankton samples were collected through horizontal hauls and were performed during day time from 1 m below the surface using a 500 µm mesh net and samples were preserved in 4% formalin in seawater for further analysis. A Hydro-Bios digital model 438 110 flow-meter was fitted to the net in order to measure the volume of water filtered. For zooplankton taxonomic and quantification analyses sub-sampled using a Folsom-splitter were used until a minimum of 500 individuals were counted. Abundance data were standardized to number of individuals per cubic meter.

2.2. Data Analysis

Only the most abundant 50 taxa out of the 90 identified, having a minimal mean occurrence of 0.1% of the total density observed in the study area were considered. This cut-off eliminated the species that occurred rarely, some being observed on few or rare occasions. Moreover, well-represented species can be viewed as potential indicators of zooplankton dynamics and ecosystem functioning.

In order to investigate the temporal and spatial variability in the zooplankton community structure, the species densities were arranged in a tridimensional matrix (species, dates and sites) comprising 50 columns and 72 rows. These data offered the possibility to study the three-dimensional array in two ways (Fig. 2): (A) the spatial variability of the zooplankton community and its dynamics in time (data were organized as a series of tables for each date, where each column corresponded to the species density and each row corresponded to a sample) and (B) the dynamic trajectories of the zooplankton community per site (data were considered as a series of tables for each site, where each column corresponded to the species density and each row corresponded to a sample). In order to down weight the influence of highly dominant species, species density was log(x+1) transformed prior to calculations [10]. Data were subjected to the PTA [7-9], which is based on the logic of the Principal Component Analysis (PCA) [11]. It is designed to study simultaneously several sub-matrices of quantitative data and to detect within the structure any pattern common to these different sub-matrices; in other words, it allows extraction of the multivariate structure that is expressed through the different dates or sites, and describes dominant patterns in its first axes. It is a multivariate technique well-adapted to the statistical study of surveys when the same variables (in this study, species density) are measured on the same individuals [7]. The general

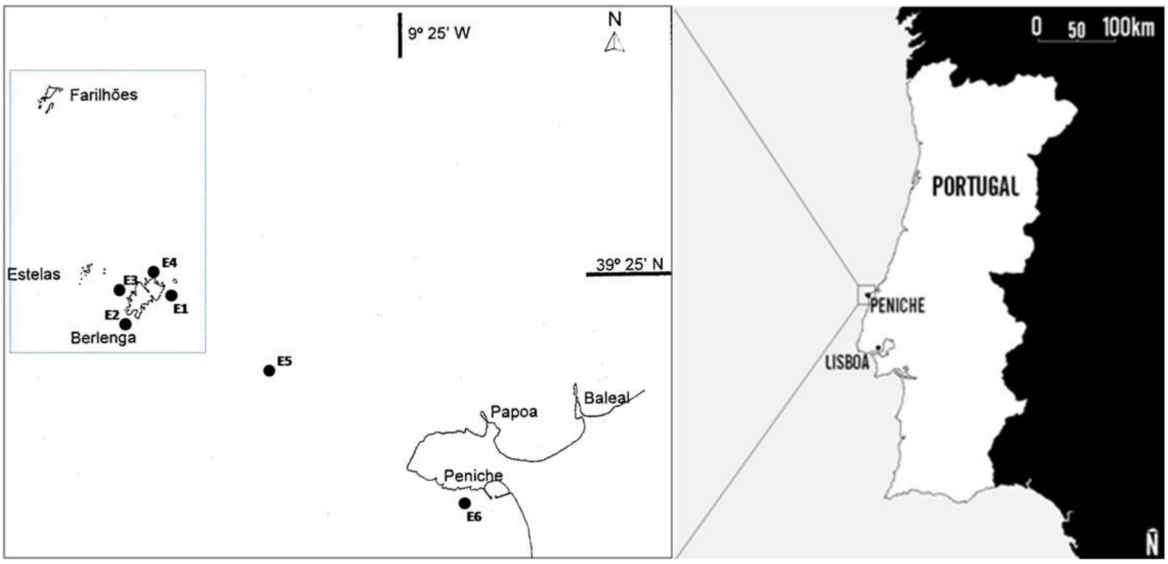

FIGURE 1 - Map of the Berlengas Archipelago and the location of the 6 sampling sites. The rectangle represents the marine protected area.

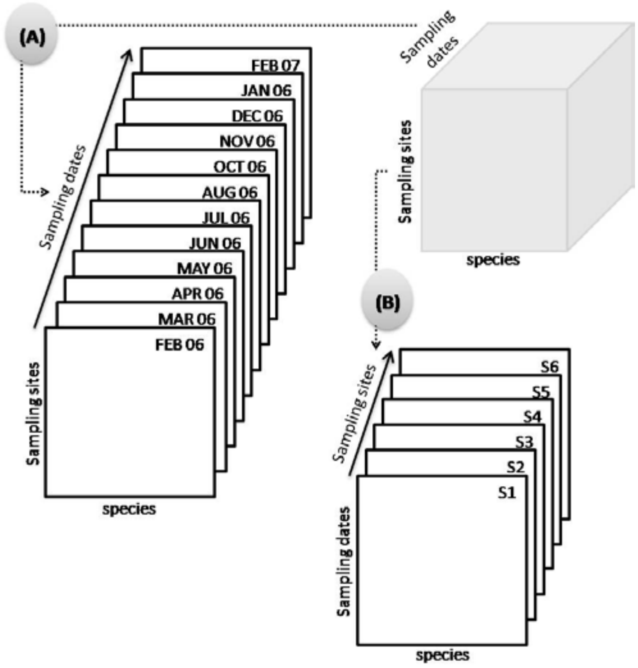

FIGURE 2 - Tridimensional table of data (dates, sites, zooplankton density) used in the PTA analysis. Way (A) – Identification of a spatial structure common to the 12 dates and study of the temporal permanence. Way (B) – Identification of a temporal structure common to the 6 sites and study of the spatial permanence.

functioning principle of PTA consists to find the common part of all separated analysis (for dates or sites). For that purpose, PTA analysis consists of successive steps: (1) the interstructure analysis provided a global description of the sampling points as a function of the typology of the sampling individuals (dates or sites). It consists of the comparison of the structure of the different sub-matrices (dates or sites) and the identification of the individuals sharing a similar structure (by the vectorial correlations presented in the matrix and calculated between dates or sites). The function of this step is to assign a weight to each sub-array and measure the contribution of each to the overall structure. Additionally, and in proportion to the weights is the $\cos^2(x)$. It constitutes an indicator of how much the overall structure expresses the information contained in each table; (2) the compromise analysis provided a description of sampling points as a function of the species typology. It was used to identify the species assemblages that characterized similar patches at different dates or sites. This leads to the establishment of a common spatial or temporal typology shared by those dates or sites, respectively; (3) finally, the analysis of the trajectories (or intrastructure) onto the compromise. The subsets are projected separately onto the compromise to highlight which date or site fits best to the compromise; in other words, allows us to draw the trajectories that represent the temporal or spatial variations of each species around the common structure. All the analyses (calculations and graphs) were run using the package ADE-4 [12]. This software is available free of charge at the following Internet address: http://pbil.univ-lyon1.fr/ADE-4.

3. RESULTS

A total of 90 taxa represented by 30 groups were encountered. Data showed that cladocerans were the most abundant group (30% of the total zooplankton), despite being restricted to warmer months (Fig. 3). Other important zooplankton groups were the copepods, a perennial group (21%), the gelatinous (13%, constituted primarily by 7% doliolids, 4% appendicularians and 2% medusae), meroplankton (18%) and siphonophores (9%). Minor groups also found in the region were euphausiaceans (3%), chaetognaths (1%) and mysidaceans (0.1%). The average abundance for the main zooplankton taxa for each sampling station is presented in Table 1. Among the cladocerans the *Penilia avirostris* were by far the most abundant species in the study area (77% Cladocera), with a limited seasonal occurrence, mostly present in summer and autumn. *Podon leuckarti* (16%) and *Evadne nordmanni* (7%) followed in abundance. More than 40 copepod species were identified during the entire study, but only 6 species accounted for

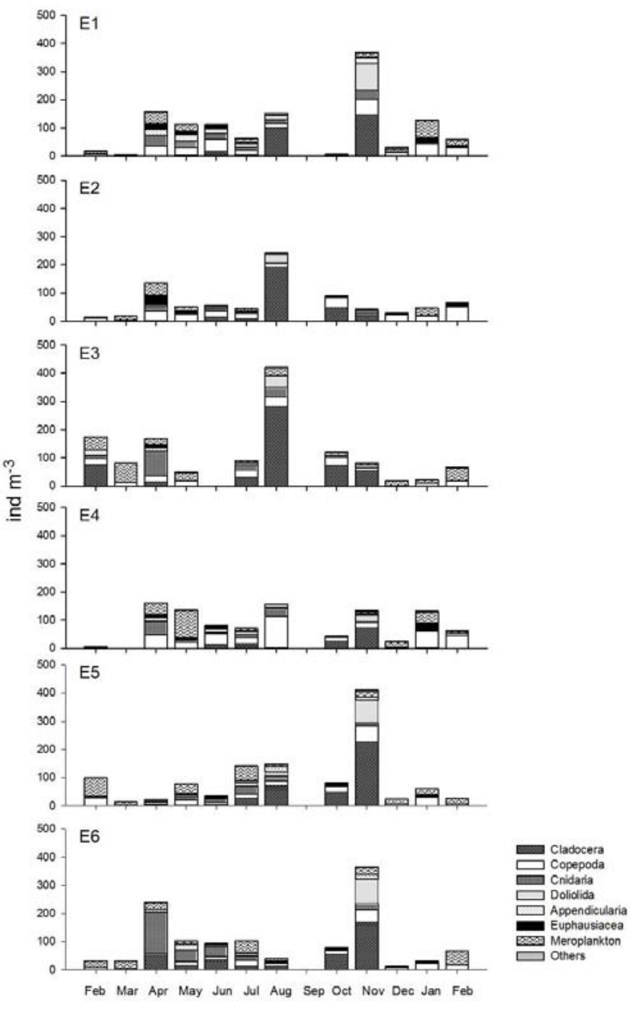

FIGURE 3 - Monthly abundance (ind m^{-3}) of the main zooplankton groups, over different sampling stations, from February 2006 until February 2007.

TABLE 1 - Annual mean abundance (ind m^{-3}) of the main zooplanktonic taxa and their standard deviation (SD) during the studied period. Species abbreviation (abbrev) used in PTA analysis.

Taxa	abbrev	E1	E2	E3	E4	E5	E6
Total abundance		1218 ±101	845 ± 64	1298 ± 113	1004 ± 58	1155 ± 109	1206 ± 103
Cladocera		292 ± 48	299 ± 55	541 ± 82	141 ± 21	394 ± 66	363 ± 49
Evadne nordmanni	ENOR	24 ± 3	9 ± 1	19 ± 2	22 ± 2	18 ± 2	53 ± 9
Penilia avirostris	PAVI	241 ± 47	258 ± 55	443 ± 81	93 ± 20	317 ± 65	216 ± 48
Podon leuckarti	PLEU	27 ± 4	31 ± 5	78 ± 12	25 ± 4	60 ± 9	94 ± 15
Copepoda		276 ± 17	245 ± 13	189 ± 10	374 ± 31	195 ± 15	168 ± 11
Acartia clausi	ACLA	15 ± 2	13 ± 1	10 ± 1	15 ± 3	12 ± 1	53 ± 5
Calanus helgolandicus	CHEL	20 ± 1	17 ± 2	9 ± 2	19 ± 2	45 ± 7	12 ± 1
Calanus helgolandicus copepodite	CHELC	40 ± 6	44 ± 6	17 ± 3	36 ± 7	11 ± 2	4 ± 1
Centropages chierchae	CCHI	94 ± 10	59 ± 5	87 ± 8	83 ± 10	64 ± 7	48 ± 5
Oithona plumifera	OITP	17 ± 3	9 ± 2	7 ± 1	87 ± 22	7 ± 1	4 ± 1
Temora stylifera	TSTY	45 ± 7	48 ± 5	27 ± 3	57 ± 9	33 ± 5	36 ± 7
Cnidaria		146 ± 14	41 ± 5	166 ± 26	107 ± 15	94 ± 9	269 ± 42
Lizzia blondina	LBLO	23 ± 4	3 ± 0	14 ± 2	22 ± 4	19 ± 3	20 ± 3
Siphonophora							
Muggiaea atlantica	MATL	110 ± 11	36 ± 5	145 ± 24	71 ± 10	72 ± 7	238 ± 38
Doliolida		139 ± 27	47 ± 9	52 ± 11	54 ± 8	108 ± 23	89 ± 25
Doliolum sp.	DOLI	139 ± 27	47 ± 9	52 ± 11	54 ± 8	108 ± 23	89 ± 25
Appendicularia		72 ± 9	18 ± 1	44 ± 6	30 ± 3	57 ± 6	68 ± 7
Fritillaria borealis	FBOR	35 ± 6	3 ± 0	5 ± 0	5 ± 1	5 ± 1	8 ± 2
Oikopleura sp.	OIKO	37 ± 5	15 ± 1	39 ± 6	25 ± 3	52 ± 5	60 ± 6
Euphausiacea		69 ± 7	60 ± 10	18 ± 3	49 ± 7	23 ± 2	10 ± 1
calyptopsis	ECAL	36 ± 4	30 ± 5	10 ± 1	31 ± 5	17 ± 1	7 ± 1
furcilia	EFUR	33 ± 4	30 ± 5	10 ± 1	31 ± 5	17 ± 1	7 ± 1
Meroplankton		202 ± 18	127 ± 12	274 ± 21	225 ± 29	261 ± 19	229 ± 15
Cirripedia nauplius	NCIRR	5 ± 1	3 ± 0	12 ± 2	7 ± 1	38 ± 10	31 ± 4
Decapoda larvae n id	DLAR	12 ± 1	9 ± 1	15 ± 2	7 ± 1	12 ± 1	28 ± 3
Zoea *Carcinus maenas*	ZCAR	87 ± 12	46 ± 6	183 ± 19	53 ± 8	141 ± 18	108 ± 11
Zoea *Pisidia longicornis*	ZPLO	2 ± 0	3 ± 0	9 ± 1	3 ± 1	7 ± 1	14 ± 1
Echinodermata larvae	ELARV	11 ± 1	3 ± 0	20 ± 4	77 ± 21	17 ± 3	29 ± 7
Ichthyoplankton		7 ± 10	5 ± 11	2 ± 3	6 ± 11	3 ± 6	11 ± 1
Fish egg	FEGG	76 ± 10	51 ± 11	25 ± 3	70 ± 11	38 ± 6	11 ± 1
Others		21 ± 2	9 ± 1	14 ± 1	24 ± 3	22 ± 2	11 ± 1

83% of total copepods. The calanoid *Centropages chierchae* was the most abundant, followed by *Temora stylifera*, *Calanus helgolandicus* (adult and copepodite development stage), *Oithona plumifera* and *Acartia clausi* (Table 1). Meroplankton such as nauplii Cirripedia, Decapoda larvae (particularly Zoea *Carcinus maenas*), Echinodermata pluteus and fish egg were also important species. The siphonophores were mainly represented by *Muggiaea atlantica* and appendicularians by *Oikopleura* spp. and *Fritillaria borealis*.

3.1. Dynamics of zooplankton community spatial variability at dates scale

The first procedure of the PTA was conducted on the 12 tables for each date, denoting the spatial variations (i.e rows = sites and columns = species density). The use of PTA showed that the vectorial correlations (RV in Table 2A) between each of the 12 months had different contributions. Moreover, these results pointed out that the strongest correlation was observed between April and May (RV = 0.73), while June and March reflected the weaker (RV = 0.16). This result highlighted the fact that the associations between species were not stable from one month to another. From the analysis of the correlations and the weights (Table 2A), the common temporal structure appeared to be stronger in November, August, April, July and May. They contributed a larger part in the definition of the compromise (meaning that the compromise will be more influenced by these dates) suggesting that the remaining sampling dates had more particular structures leading to a weaker weight. Finally, by the $cos^2(x)$ (Table 2A) was possible to evaluate how much the compromise expresses the information contained in each table. July ($cos^2(x) = 0.68$) was the month that fits best with the compromise, followed by November ($cos^2(x) = 0.63$). By other way, the compromise represented with less accuracy the zooplankton dynamics in December and March ($cos^2(x) = 0.19$ and $cos^2(x) = 0.17$, respectively).

The projection of the sampling sites on the first principal plan 1-2 provides a graphical representation of the compromise, whose interpretation requires consideration of the correspondences with the species (Fig. 4A). The eigenvalues diagram (Fig. 4A1) shows that the first axis was clearly dominant (account for 94% of the explained variance) in contrast with the second axis (4% of the explained variance) which was less significant. Therefore, they provided a good summary and typology of the spatial species organization, on the basis of the common structure, over the 12 sampling dates. The factor plots of the first

TABLE 2 - Typological value indices. Matrix of correlation between surveys (RV) and description of the structure defined for each survey. (A) Temporal scale and (B) spatial scale. Weights (contribution of each table in the construction of the compromise); $Cos^2(x)$ (fit of each table to the compromise).

A

Sampling date	RV												Weight	$Cos^2(x)$
Feb 06	1												0.19	0.31
Mar 06	0.54	1											0.09	0.17
Apr 06	0.37	0.29	1										0.37	0.51
May 06	0.34	0.38	0.73	1									0.32	0.53
Jun 06	0.19	0.16	0.51	0.61	1								0.27	0.53
Jul 06	0.42	0.29	0.62	0.64	0.69	1							0.36	0.68
Aug 06	0.42	0.22	0.39	0.39	0.44	0.59	1						0.38	0.53
Oct 06	0.44	0.23	0.28	0.28	0.34	0.43	0.63	1					0.23	0.45
Nov 06	0.35	0.17	0.33	0.39	0.54	0.55	0.67	0.68	1				0.44	0.62
Dec 06	0.44	0.41	0.23	0.30	0.22	0.26	0.22	0.24	0.34	1			0.10	0.19
Jan 07	0.46	0.42	0.47	0.56	0.50	0.49	0.36	0.42	0.47	0.53	1		0.27	0.48
Feb 07	0.46	0.55	0.38	0.40	0.34	0.40	0.30	0.31	0.36	0.50	0.55	1	0.20	0.32

B

Sampling site	RV						Weight	$Cos^2(x)$
E1	1						0.47	0.68
E2	0.75	1					0.36	0.59
E3	0.64	0.70	1				0.39	0.55
E4	0.76	0.66	0.53	1			0.39	0.54
E5	0.78	0.67	0.67	0.64	1		0.43	0.65
E6	0.69	0.59	0.59	0.59	0.75	1	0.40	0.55

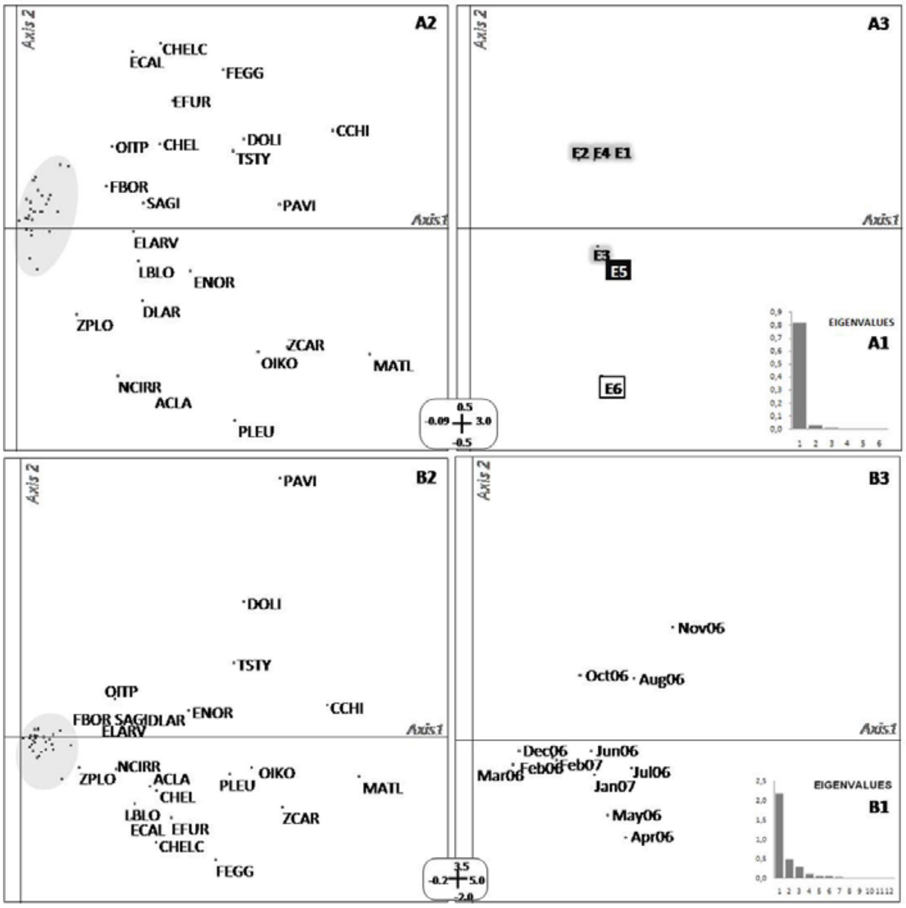

FIGURE 4 - Compromise factor maps of the PTA analysis. (A) Dynamics of zooplankton spatial variability at the temporal scale: (A1) Eigenvalues bar plot of the compromise; (A2) Zooplankton density projected on the first factorial plan; (A3) Sampling sites projected on the same factorial plan. (B) Variability of the zooplankton dynamics at the spatial scale: (B1) Eigenvalues bar plot of the compromise; (B2) Zooplankton density projected on the first factorial plan; (B3) Sampling dates projected on the same factorial plan. Only the labels of most abundant species and thus of importance in these graphics, were identified for clarity. Species codes according Table 1. Each date is identified by the three first letters of the month (e.g. Feb07 – February 2007). Axis 1 - the first principal component; Axis 2 - the second principal component. The scales of the graphs are given in the rounded box. Note for different scales.

two axes of the compromise analysis are shown for the zooplankton community (Fig. 4A2) and sites (Fig. 4A3). In order to facilitate the interpretation, only the most abundant species were identified in the graph (see Table 1 for code correspondence). The analysis of the first principal plan (Fig. 4A) distinguished three zones characterized by its particular species composition: one related to the inshore station E6, the second zone comprises stations with different characteristics, a shelf station (E5) and an offshore station (E3), and finally one zone that group the further offshore stations (E1, E2, E4). Axis 2 mainly opposed homogeneous stations (E1, E2, and E4; Fig. 4A3) dominated mainly by *C. chierchae*, *P. avirostri, T. stylifera* and *Doliolum* spp. to stations less homogeneous (E3, E5 and E6). The second zone defines a transition area characterized by the occurrence of echinodermata and decapoda larvae, the cladoceran *E. nordmanni* and medusae *L. blondina*. Finally, the siphonophore *M. atlantica*, the appendicularians *Oikopleura* sp., and meroplanktonic larvae such as Zoea of *C. maenas* and nauplii of cirripedia, and the cladoceran *P. leuckarti* were clearly under the influence of the characteristics of the neritic station E6. The trajectories of the compromise for the sampling dates were represented for species (Fig. 5A1) and for sites (Fig. 5A2). It allows us to identify temporal patterns for the species and sites around the common structure. The trajectories maps focused on November, August, April, July and May, when the observed co-structure of species densities was the most significant (see Table 2A). The projection of species variables for each month on the compromise plan showed that each one is close to the compromise structure (see Fig. 4A), which confirms that the analysis is in accordance with the pattern pointed out by the compromise.

The projection of each table-date in plan 1-2 of the compromise (Fig. 5A1) showed that *P. avirostris* exhibited the strongest temporal variation. The density found for this species was particularly lower in April, May, June and July, in contrast with August and November. It was the clear seasonal dynamics of *P. avirostris*, in conjunction with some Copepoda species (e.g. *O. plumifera, C. chierchae, T. stylifera*), that strongly affected the structure of zooplankton community and caused the observed pattern between E1, E3 and E5 (Fig. 5A2) in these two months. Moreover, *Doliolum* sp. and *P. avirostris* appeared as the dominant species during this period, following a similar pattern, however the former species showed an earlier increase in abundance (June and July). *M. atlantica* was the most stable during the study period, with its position always in the negative half of axis 2. Also, *P. leuckarti* follow this pattern with an exception for June, where it appeared closer to *Doliolum* sp. and *C. chierchae*. Regarding the period in analysis, the inshore station E6 was always located in the negative half of axis 2 (Fig. 5A2). Furthermore, while in May and November, offshore sites were in opposition to E6, in July those sites had the particularity of being nearest the inshore station, indicating a similar pattern in species composition. In addition, the dynamics between E4 and E2, from July to August, resulted in a general increase of *P. avirostris* and a decrease of Echinodermata larvae and *A. clausi* (Fig. 5A1 and 5A2). To summarize, based on the analysis of the two representations of the trajectories, the conditions of the sites showed a more pronounced stability over time compared with the annual pattern of the species distribution.

3.2. Variability of zooplankton community dynamics at the site scale

The second procedure of the PTA was performed on the 6 tables for each site, denoting the temporal variations (rows = dates and columns = species density).

The matrix presenting the RV between the sampling sites sub-matrices (Table 2B) showed that the strongest correlation (RV = 0.78) was observed between the sites E1 and E5 whereas the sites E3 and E4 pointed out the weakest one (RV = 0.53). Also, it was observed that the contribution of the different sampling sites for the construction of the compromise, were well-balanced (weighting 0.36-0.47). However, the sub-matrices E1, E5 and E6 contributed a major part in the definition of the compromise (0.47, 0.43, 0.40, respectively) suggesting that other sites had more particular structures (leading to a lower weight). The observation of the $\cos^2(x)$ (Table 2B) indicates that E1 was the one that fits the best with the compromise ($\cos^2(x) = 0.68$), followed by stations E5 ($\cos^2(x) = 0.65$) and E2 ($\cos^2(x) = 0.59$). On the other hand, for the stations E3, E6 and E4, the compromise represented with less precision the annual dynamics of zooplankton ($\cos^2(x) = 0.55$, 0.55 and 0.54, respectively).

The projection of the species on the plan 1–2 (Fig. 4B2) provides a graphical representation of the compromise, whose interpretation requires consideration of the correspondences with the months (Fig. 4B3). The first two axes of the compromise accounted for 82% of the total inertia with 67% for axis 1 and 15% for axis 2 (Fig. 4B1). They provided a good summary of the temporal species organization over the 6 sampling stations for the 12 sampling months. As previously, only the most abundant species were identified in the graph (see Table 1 for code correspondence).

The first axis distinguished a group of species that were typical of warmer months such as *C. chierchae* and *M. atlantica* and to a lesser extent Zoea *C. maenas*, *Oikopleura* sp., *T. stylifera* and *P. leuckarti*. These were all observed to be relatively more common between June to November (Fig. 4B3).

The second axis was defined by two distinct species assemblages. One assemblage was mainly dominated by *P. avirostris* and *Doliolum* sp. whereas the second one was essentially composed by fish eggs and *C. helgolandicus* (copepodites and adults). In addition, the distribution of the sampling dates on the compromise reflected a transition from April-June to August-November (Fig. 4B3).

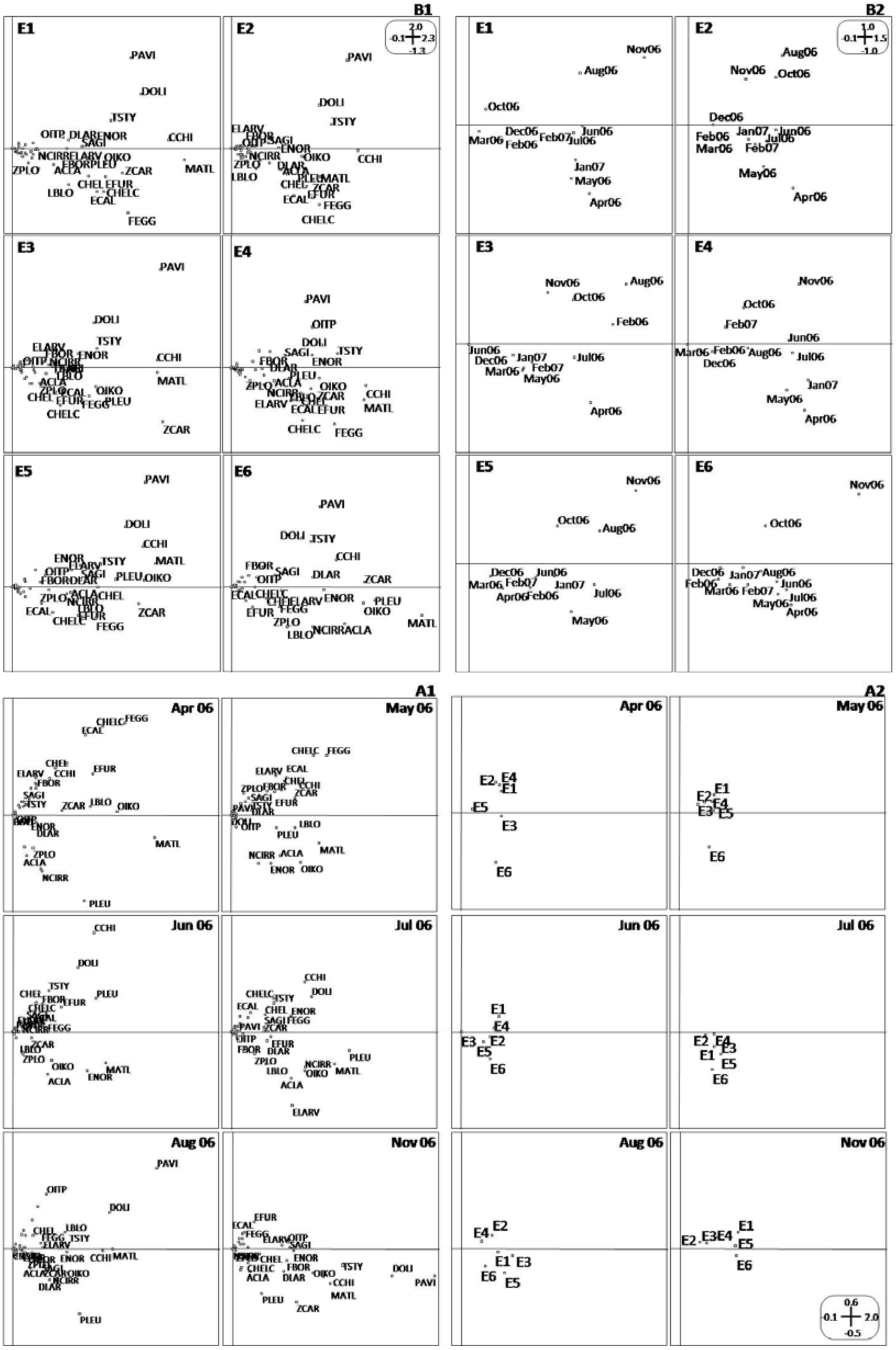

FIGURE 5 - Trajectories factor plots of the PTA analysis. (A) Dynamics of zooplankton spatial variability at the temporal scale: (A1) Projection of the zooplankton species on the first factorial plan (only for species that stood out on the compromise diagram, see Fig. 4A2). (A2) Projection of the sampling stations on the first factorial plan. Graphs are given only for the 6 dates that showed the highest contribution to the compromise (see Table 2A). (B) Variability of the zooplankton dynamics at the spatial scale: (B1) Projection of the zooplankton species on the first factorial plan (only for species that stood out on the compromise diagram, see Fig. 4B2). (B2) Projection of the sampling dates on the first factorial plan. Species codes according Table 1. Legend of the months according Fig. 4. Axis 1- the first principal component; Axis 2 - the second principal component. The scales for axes are given in the rounded box.

From the separated analyses of each table, the compromise of species (Fig. 5B1) and dates (Fig. 5B2) has been projected onto the first principal plan. This allowed the discussion of the spatial variations of species and dates, i.e. the internal structure of each table per site. Generally, these projections were in agreement with the patterns noted by the compromise. However, the analysis can be mainly focused on sampling stations E1 and E5, since its general pattern of species and dates distribution, is what is more aligned with the compromise (Fig. 5B). This observation implies that there were a few differences between seasonal changes in the composition of the zooplankton community for these two sites and the compromise. Moreover, this confirms the information given by the values of the weights and the $\cos^2(x)$ (see Table 2B). Although slight, the general pattern observed for the stations E2, E3, E4 and E6, for the distribution of dates and species (see Fig. 5B1 and Fig. 5B2) differed from the distribution achieved by the compromise. Even though not very strong, they had their own internal typology (each sites presented a particular species composition and abundance dynamic) which indicates that the zooplankton community was characterized by its own seasonal dynamics for those sampling stations.

4. DISCUSSION AND CONCLUSIONS

The analysis of zooplankton community in the upper waters of the shelf area of Berlengas Natural Reserve (NW Portugal) suggested high species diversity, with 90 species/genera recorded. Data from zooplankton samples showed that cladocerans were the most abundant group (30% of the total zooplankton), but restricted to warm periods. An important perennial group was represented by copepods (21%). It is worth stressing the importance of these taxa in offshore zooplankton studies, as has been already observed off the NW Iberian Peninsula [13-15] and in other coastal areas [16, 17]. In the region, these groups have been also highlighted as the most abundant by a previous study performed by Pardal and Azeiteiro [6].

The PTA method showed the similarities between the successive data tables (arranged according to different scales, time vs. space) and proved to be useful for investigating biotic structures and detecting different patterns in the temporal development and spatial distribution of zooplankton communities. Therefore, regarding the zooplankton abundance pattern and the species association it was possible to distinguish a pattern related to a neritic-ocean gradient of the zooplankton composition and a temporal variability. In addition, following the analysis of the principal factor plan, four distinct periods can be highlighted considering the distribution of the dates and the arrangement of the species on the first two axes: (i) the first one comprised August to November, (ii) the second one was related to June and July, (iii) the third one associated with spring (April and May) and, (iv) the latest one was related to winter (February, March and December 2006 and January and February 2007).

The geographic location of the Berlengas Archipelago and the specific hydrographic conditions in the area were clearly important in structuring the zooplankton community. As observed in other coastal areas, associated with upwelling events, shelf and oceanic sites have different zooplankton composition in response to different hydrographic conditions [17,18]. The hydrodynamics off the Portugal coast has been described by several authors (e.g. [1, 19]). As described, the general surface circulation follows a seasonal pattern. Wind regime seasonality can be very important in the shelf currents in the region [20]. Dominant south-westerly winds in autumn-winter induce downwelling and favour poleward flow (IPC), while dominant northerly winds in spring-summer are associated with coastal upwelling and equatorward flow [5]. The transition from winter downwelling to summer upwelling conditions occurs around April [21]. This transition is reflected in the large variability in circulation and in the distribution of physical properties, observed both on the shelf and offshore. These seasonal changes in the currents flowing along the Portuguese coast and the different upwelling patterns originated by differences in the shelf topography were reflected in the changes in the horizontal distribution of zoo-plankton. According to PTA analysis was possible to define 3 spatial areas based on species composition. What emerges from our results is that the inshore region was the more unstable, owing to the influence of upwelling events. Indeed different species-assemblages were observed during the study period at that station. Taxa linked to high phytoplankton concentrations such as *C. helgolandicus* and *Calanoides carinatus* [22] dominated during warmer months, which coincide with upwelled waters, rich nutrient waters that favored phytoplankton development/spring bloom [23]. Furthermore, it is noteworthy that during the warmer months (between August to October) a considerable increase in the abundance of cladocerans was observed, mainly due to *P. avirostris*. This species is one of the more abundant and widespread members of the crustacean zooplankton in nearshore tropical and subtropical waters [24], although recently it has spread to higher latitudes (e.g. the North Sea, [25]). It seems that its occurrence is mainly related to the availability of adequate food. *P. avirostris* ingests a wide spectrum of microbial organisms, from flagellates <2 mm to chain-forming diatoms, showing a clear advantage over copepods [26]. In addition, it is known that among the different phytoplankton groups observed in coastal upwelling ecosystems, diatoms and dinoflagellates can take advantage of different oceanographic conditions [23,27,28], since those organisms are the main food source of *P. avirostris*, that situation could be positive for their positive development. Besides, during the study period, regional and local climate showed a general pattern toward dried and warmer conditions which extend through-outthroughout the autumn period, as indicated by a reduction in precipitation and a warming of air temperatures (http://web.meteo.pt/pt/clima/clima.jsp). These conditions could favour a dominance of flagellates resulting in a change in food availability for *P. avirostris*. Another feature that can distinguish species from continental shelf and more offshore sites during stratified waters was species linked to lower salinity, such as *A. clausi* and meroplankton, which are quite common inshore.

A good knowledge of the geographical distribution of the species-assemblages and their temporal variability is crucial to facilitate and detect ecological interpretation. However, we recognize that monitoring the dynamics of pelagic ecosystems at long-term time series is needed in order to be aware of important aspects such as global warming trend on marine communities, invasion of exotic species ("biologic pollution"), and to identify the important species or groups that can act as indicator of global changes or environmental contaminants [29]. As denoted by [30] the decrease in subarctic species, associated with an increase in temperate pseudoceanic species, have a possible link with change along the European shelf-edge. For all the mentioned aspects, the Berlengas Natural Reserve (NW Portugal), due to their special hydrodynamics features, can be considered a suitable area to biological long-term studies to detect changes, at local but also at regional scale. More studies should be conducted in near future in order to better understanding the zooplankton dynamics and their relationship with hydrodynamic processes that occur on the west coast of Portugal, and namely on the vicinity of Berlengas Natural Reserve as a consequence of the Nazaré submarine canyon.

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